The Economic Impacts Of Climate Change On The Chilean Agricultural Sector.

The agricultural sector could be one of the most vulnerable economic sectors to the impacts of climate change in the coming decades. Climate change impacts are related to changes in the growth period, extreme weather events, and changes in temperature and precipitation patterns, among others. All of these impacts may have significant consequences on agricultural production (Bates, *et al.* 2008).

A main issue regarding climate change impacts is related to the uncertainty associated with their occurrence. Climate change impacts can be estimated with simulation models based on several assumptions, among which the future patterns of emissions of greenhouse gasses are quite likely the most relevant, driving the development of future scenarios, i.e. plausible visions of how the future may unfold. Those scenarios are developed as storylines associated with different assumptions about climate and socioeconomic conditions and emissions, with reference figures, such as demographic projections, average global temperatures, etc. (Intergovernmental Panel on Climate Change 2000). Within this context, climate change impact assessment is forced to consider multiple and interconnected sources of uncertainty in order to produce valuable information for policymakers.

The effectiveness of public policies developed by policymakers will thus depend not only on local characteristics, such as climate and socioeconomic conditions, but also on global scenarios. In order to address the challenges imposed by climate change from an economic perspective, an approach that provides a detailed picture of the agricultural sector and the relationships within it, is essential. In this regard, bottom-up approaches (i.e. in particular models applied at local level, but driven by global scenario driving forces) could be an effective tool to evaluate the economic impacts of climate change on the agricultural sector.

Bottom-up approaches, such as bio-economic agricultural models, simulate the agents' (e.g. farmers') behavior, allowing for an *ex-ante* evaluation of policy interventions. Agricultural models range from studies at farm level, to studies including the whole agricultural sector. The main difference is in the distinction between endogenous and exogenous variables and in particular price assumptions.

Agricultural supply models represent the agricultural sector through a series of behavioral equations, which are solved in order to maximize the farm income or the regional income, subject to technological, environmental, and institutional constraints. (Howitt 2005).

The wide use of agricultural models is underpinned in the limited amount of data required for their development. This feature is well appreciated, especially by researchers conducting studies in developing countries. (Howitt 1995, Hazzel and Norton 1986).

Agricultural supply models in their multiple versions have been applied to several agricultural issues, like models analyzing the expected impacts of the Common Agricultural Policy (CAP) in regions like Belgium, UK, Greece, Germany, and Sweden. (Mattas, *et al.* 2011, de Frahan, *et al.* 2007, Blanco, *et al.* 2008). Other applications include the estimation of the economic value of water and land (Medellín-Azuara, *et al*. 2009, Howitt, *et al.* 2001, Iglesias and Blanco, 2008, Kan, *et al.* 2009), climate change impacts (Howitt, *et al.* 2009, Henseler, *et al.* 2009). For reviews of other case studies see Heckelei *et al* (2012).

The economic assessment of climate change impacts on the Chilean agricultural sector has been widely analyzed from different perspectives in recent years. The first study on this subject was conducted by the University of Chile's AGRIMED center in 2008 (Santibanez, *et al.* 2008). In this study, authors analyzed the productive impacts that climate change could produce within the Chilean agricultural sector. In order to analyze the expected impacts new climate conditions would have on different agricultural activities, they used the SIMPROC model. The results are computed at the commune level (340 communes), while the scenarios modeled are the IPCC A2 and B2 for two time periods, around 2040 and 2070 (Intergovernmental Panel on Climate Change 2000). According to the results, the most affected activities by impacts of climate change are located in the northern region of Chile.

In 2009, the Economic Commission for Latin America and the Caribbean (CEPAL) conducted a study analyzing the economic impacts of climate change in Chile (CEPAL 2009). Although the study does not focus on the agricultural sector, this sector is analyzed as part of the Chilean economy. Using an econometric model, the authors simulated the expected changes in land allocation due to climate change. The analyzed crop yield changes and activities are those used by Santibáñez, *et al.* (2008). Their results suggest that net incomes will increase from the Biobío region to the south, while in the northern region the net incomes will decrease. In the worst-case scenario, the agricultural sector will loose 15% of its income (A2 scenario), while in the best scenario the incomes will increase by 1% (B2 scenario).

Finally, in 2010 the Chilean Agricultural Agency conducted a study at the national level in order to account for the magnitude of the economic impacts climate change could have on the Chilean agricultural sector (ODEPA 2010). The study updates the information generated by Santibáñez, *et al*. (2008), increasing the number of activities analyzed, from 17 to 25. In this study, the authors used an econometric model in order to account for the land allocation change due to expected yield changes. The main conclusions of the study show that climate change will have uneven impacts across the country, with the northern region being the most affected. Results also show a southward movement of the land allocated to annual crops and cereals. In general terms, a 7% decrease in the land devoted to cereal and fruit production is expected under the A2-2040 scenario, while the net income decreases by 5%.

In general, the use of agricultural models has been focused to policy analysis, with few studies addressing climate change impacts. On the other hand, climate change impacts on the Chilean agricultural sector have mainly been analyzed through the use of econometric techniques, or using simple accounting methods.

This paper presents a non-linear agricultural supply model for the analysis of the economic impacts of changes in agricultural yields due to climate change. The model's structure is designed to be used within a context of information restriction, this feature is especially valuable for use in developing countries. The agricultural model is designed specifically for the analysis of the Chilean agricultural sector, and it accounts for uncertainty through the use of Monte Carlo simulations about agricultural yields.

METHODOLOGY

Model Description

The Agricultural Supply model (ASM) is a mathematical programming model designed to analyze the agricultural sector with high geographical disaggregation. It includes the major agricultural activities within the area, and differentiates between water provision systems (rainfed and irrigated), among other features.

The core of the ASM includes the behavior of the agricultural producers, which is characterized by detailed information at the producer level in order to represent a system of outputs supply and inputs demand, which is the result of the assumed profit maximization behavior. The information is differentiated by activity and geographical area, including: area planted, yield, variable costs, and labor demand, which is used to compute total costs, gross margin, and net revenues. The information presented above is complemented with supply elasticities for each activity. The core model is optimized considering a series of endowment restrictions, such as: total land, irrigated land, and water availability. Using Positive Mathematical Programming (PMP), the model is calibrated to the reference period. Using this method it is possible to achieve a perfect calibration for area planted avoiding the dependency between parameters and constraints (Howitt 1995).

Model Structure

The model's development involves a three-step procedure. In the first step, a mathematical programming model is built in order to maximize the region's farm net income by allocating land and irrigation water to crops. This model takes all relevant data and farming conditions into account, and includes: 1) the objective function describing the farmers' behavior as rational agents; 2) the set of explicit constraints related to resource availability (land, irrigated land, water) and institutional conditions (policy and environmental).

The main decision variables are cropland allocation and irrigation technology choice. $X_{r,a,s}$ denotes the area (ha) allocated to crop *a* with farming system *s* in region *r*. The model can be compactly written as (subscript *i* denotes the resource type):

$$Z = \sum_r \sum_a \sum_s \left(p_a * y_{r,a,s} - AC_{r,a,s} \right) * X_{r,a,s} \quad [1]$$

$$AC_{r,a,s} = v\cos t_{r,a,s} \quad [2]$$

$$\sum_a \sum_s r_{i,r,a,s} * X_{r,a,s} \leq b_{i,r} \quad [3]$$

$$X_{r,a,s} \geq 0 \quad [4]$$

In equation [1], *Z* denotes the objective function value, $AC_{r,a,s}$ is the vector of average costs per unit of activity, $v\cos t_{r,a,s}$ represents the observed variable costs per unit of activity. In equation [1] p_a is the price of crop *a*, $y_{r,a,s}$ is the yield per hectare of crop *a*, in region *r*, using system *s*. In equation [3] $r_{r,a,s}$ represents the matrix of coefficients in resource/policy constraints, and $b_{i,r}$ is the vector of available resource quantities. Finally, equation [4] represents the non-negativity constraints on land allocation.

In the second step, a non-linear objective function is calibrated using PMP based on observed activity levels for the base situation. The model assumes constant average revenues (regardless of the level of activity) and increasing average costs, as well as a non-linear cost function, which captures all production conditions not explicitly modeled. Following Blanco *et al*, (2008), the average cost function of activity *a* can be written:

$$AC_{r,a,s} = \alpha_{r,a,s} * \left(X_{r,a,s} \right)^{\beta_{r,a,s}} \quad [5]$$

The cost function parameters $\alpha_{r,a,s}$ and $\beta_{r,a,s}$ are derived from a profit-maximizing equilibrium that maximizes equation [1] subject to [3], [4], and [6].

Additional conditions are: 1) In the base-run, the estimated average cost equals the observed average cost for each activity; 2) supply elasticities are exogenous; 3) The assumption of optimal farmers' behavior can be extended to new activities, and cost function parameters can then be approximated by means of optimality conditions.

In the third step, once the cost function parameters have been derived, the calibrated non-linear model is specified. The ASM maximizes the net income [1] subject to [3], [4], and [5]. The final model is presented below.

$$Z = \sum_r \sum_a \sum_s \left(p_a * y_{r,a,s} - AC_{r,a,s} \right) * X_{r,a,s}$$

$$\sum_a \sum_s r_{i,r,a,s} * X_{r,a,s} \leq b_{i,r}$$

$$X_{r,a,s} \geq 0$$

$$AC_{r,a,s} = \alpha_{r,a,s} * \left(X_{r,a,s} \right)^{\beta_{r,a,s}}$$

The model as presented above reproduces the activity levels observed for the base-run and allows us to simulate hypothetical climate change scenarios. The model structure is flexible enough to incorporate all relevant environmental constraints and policy instruments.

Uncertainty is included in the modeling framework using the Monte Carlo method. In this specific case, the model assumes that the agricultural yields are random variables following a Gamma distribution. Thus, several sets of agricultural yields are simulated using both uniform pseudo-random numbers and the inverse probability distribution function (Hardaker, Huirne and Anderson 1997).

RESULTS

Due to its geographical characteristics, Chile has diverse climatic conditions throughout its diverse regions. The climate ranges from desert in the north, to alpine tundra and glaciers in the eastern and southeastern areas. At the administrative scale, northern Chile, characterized by an arid and semiarid climate, includes regions [XV-III]. Central Chile, characterized by a Mediterranean climate, includes regions [IV-VIII]. Southern Chile, characterized by an oceanic climate, includes regions [IX-IX], while the austral area, characterized by a sub-polar climate, includes the XII region.

Within the climatic context presented above, the total agricultural land (18.4 million ha) is divided as follows: 1.7 million ha of cultivated land, 14.03 million ha of grassland, and 2.7 million ha of forested land. Considering only the cultivated land (1.7 million ha), 76% is devoted to annual and permanent crops, while 23.5% is devoted to fodder (INE 2007).

The application of the agricultural supply model includes a smaller area than those considered in previous studies. The area being analyzed here includes regions from Atacama in the north to Los Lagos in the south. This area includes 265 communes, grouped into 36 provinces, and 10 regions. The agricultural sector is represented by 22 activities, aggregated according to the following categories: Crops (10), Fruits (10), and Forestry (2); the model considers irrigated and rainfed activities, accounting for 3.3 million ha.

The crops considered are: rice (irrigated), oats (rainfed), common beans (irrigated), maize (irrigated), potatoes (irrigated and rainfed), alfalfa (irrigated), sugar beet (irrigated), and wheat (irrigated and rainfed). The fruits considered are: cherries, plums, peaches, apples, oranges, walnuts, olives, avocadoes, pears, grapes, and vine grapes, all of them irrigated activities. Finally, the model also includes the area devoted to forestry, including: pine and eucalyptus, both rainfed activities. The agricultural sector depicted above represents 82.4% of the agricultural activities developed within the study area[1].

The core information used in the model (area, production, yield) is from the year 2007, and comes from the National Agricultural Census (INE 2007), considering a disaggregation at communal level. The

[1] The model accounts only for those activities that have a market price, excluding grassland from the analysis.

information about costs per commune, activities and watering systems (irrigated, rainfed), as well as labor intensity is the same information that was used in the ODEPA study (ODEPA 2010). Prices were taken from the Agricultural Agency's website (ODEPA 2010), while the elasticities used to calibrate the model were collected from previous studies (Quiroz, *et al*. 1995, Foster, *et al.* 2011, CAPRI Model 2008).

Climate change impacts are simulated by changes in agricultural yields. The changes in agricultural yields are those computed by Santibáñez *et al.* (2008) through the use of the SIMPROC crop model assuming the A2 scenario in 2040. The potential agricultural yields by Zone are presented in Table 1, in which Northern Zone includes the regions: Atacama, Coquimbo and Valparaiso, Central Zone includes: Meteopolitana, O'higgins, and Maule regions, while Southern Zone includes Biobío, Araucania, Los Rios, and Los Lagos regions. The ASM is developed using the General Algebraic Modeling System (GAMS) software.

Results

At the national level, the expected changes in agricultural yields have a minor impact on the total land allocation, with total agricultural land decreasing by 46,600 ha. However, as expected the estimated impacts across regions is uneven, with the largest impacts in the northern region. For instance, both the Atacama region and the Coquimbo region decrease their agricultural land by 40%, while for the Central region the decrease is only 7.4% (on average), with a decrease of 14,825 ha. On the other hand, from the Biobío region to the south, the decrease in agricultural land is negligible.

Results by zone and activity show that there is not a direct relationship between the expected change in agricultural yields and the final change in land allocation. This apparent contradiction is because the final land allocated to each activity is function of its relative profit respect to the other activities. In this regard, the agricultural yields are one component of the profit level, along with prices and costs. For instance, within the Northern zone, on the average, the agricultural yields will decrease 51% with respect to the baseline, while the expected average change in land allocation is -16%. The same happens within the Central and Southern zone, in which a large change in agricultural yields (-24%) is foreseen, but the change in total agricultural land is quite small, -2.5% and -0.1% respectively.

At activity level, in the Northern zone a decrease on irrigated potatoes yields of 58% drives a 98% decrease on its land allocation.. This final land allocation is showing that despite the high potential productivity of rainfed potatoes under the climate change scenario, this activity is less profitable than forest production, which actually increases its land allocation.

Within the Central zone, the increase in rainfed potatoes yield (from 3.9 ton/ha to 11.9 ton/ha) would drive an increase of 9 times in the land allocated to it. On the other hand, a decrease on sugar beet yields (60%) drives a small decrease on the land allocated to this crop (4%). The same happened with the land allocated to rice that increases 1.5% regardless the large decrease on yields (-42%).

The Southern zone shows an increase on the land allocated to crops (26%) despite the expected decrease on crop yield (-26.6%). Within crops, only alfalfa, rice, and sugar beet show a decrease in their land allocation. Regarding fruits, the land allocated to avocadoes will increase 13%, independently of the expected change in yields (-55%), the same happens with the land allocated to oranges.

Agricultural production suffers large changes due to the new land allocation across the country, with the largest negative changes faced by grapes (-86%), pears (-54%), and walnut (-38%). On the other hand, most of the increase in production is associated to rainfed activities, such as: oat (125%), potatoes (84%), and wheat (38%). In general, the total agricultural production changes from 10,6 million ton to 10,5 million ton. Results by zone and activity show that the impact on crop production is unevenly distributed across the country, with crop production decreasing by 37% in the Northern zone, while in the Southern zone it increases by 38%. Fruit production decreases in all regions, ranging from 53% in the Northern zone to 11% in the Southern zone. Forest increases its production in the northern zone (8%), while the central and southern zones show a small decrease, 4% and 2% respectively.

In average, the Northern zone will decrease its agricultural production by 492,000 ton (-48%). Among crops within the Northern zone maize, potato, and wheat show the main decrease, 83%, 99%, and 52%, equivalent to 92,800 ton. On the other hand, this zone will lose 401,000 ton of fruits (-53%), with grapes, pears, and olives as the most affected activities.

The largest impact of climate change on the Central zone is represented by the 19% decrease on fruits production (627,000 ton). Most of this decrease is related to apples (262,000 ton) and vineyard (267,000 ton), which represents -84% of apple production and -69% of vineyard production. Regarding crop production, it is expected a decrease in production of 127,000 ton (6%), with maize and potatoes accounting for the large share.

The Southern zone shows the largest decrease in production with 1,142,000 ton, representing 28% of its production. Detailed results show that crop production increases 1,198,000 ton (38%), fruits production decreases by 11% (45,000 ton), and forest production decreases by 2% (10,400 ton). Among crops, oat and potatoes increase their production more than 100%, followed by wheat (46%). Pear and apple production show the largest decrease in production, 61% and 25% respectively, while the other fruit activities increase their production within the range 6% - 39%.

All the changes described above drive a 2.7% decrease in the agricultural net income, from USD 2,235 million to USD 2,176 million (equivalent to USD 59 million). At the regional level, 6 out of 10 regions show a decrease in net incomes, from Atacama to Maule. Only the regions within the Southern zone could have benefits due to climate change.

In relative terms, the regions within the Northern zone decrease their net income by 50%, in the Central zone the reduction is -17%, while the Southern zone increases its income by 40%. At regional level, the most affected region appears to be Atacama, while the region that gains the most is Los Lagos. In Atacama the impacts are associated to the decrease in production of olive, potatoes, vineyard, and avocadoes, this activities account for the 97% of the change in the agricultural production within the region. On the other hand, our simulations show that Los Lagos region doubles its agricultural production, with potatoes, wheat, and oat as the most important activities. A detailed picture at national level is presented in table 2.

Regarding activities, the distributional effects among farmers are large. Annual crop producers are better-off under the climate change scenario, than in the baseline, while fruits producers are worst-off under the climate change scenario. Farmers growing rainfed crops increase their net income by 88% (in average), with oat (132%), potatoes (93%), and wheat (39%) as the most profitable activities. In general, farmers growing crops will increase their income by USD141 million. On the other hand, only those farmers growing cherry, oranges, and avocadoes will increase their income (USD 24 million), while those growing grapes and apples will decrease their income in USD157 million. In general, fruits producers will decrease their income by USD 208 million.

All the results were presented so far as crisp values, without consideration of probabilities and uncertainty. In order to account for the uncertainty associated to the change in agricultural yields, a series of Monte Carlo simulations were developed. The objective is to determine the probability of a certain income level's occurrence, depending on the yield scenario analyzed. As it was established before, our model assumes that the agricultural yields follow a Gamma distribution. For simplicity, the Gamma distribution parameters are computed per activity for the whole country, using the mean and the variance of the agricultural yield sample. In order to compute the cumulative distribution function (CDF) for the net income a series of 400 yield scenarios were computed. The CDF is presented in Figure 1.

The analysis of the distribution shows that the 25th percentile is USD 627 million, the 50th percentile is USD1,155 million, and the 75th percentile is USD2,083 million. Considering these figures, the income reported for the climate change scenario, USD 2,176 million, is above the 75th percentile, thus supporting the robustness of results obtained, even when consideration of yield variability is included in the calculations.

CONCLUSIONS

Climate change will have vast and diverse impacts on the agricultural sector across the world, with developing countries presenting the most vulnerable regions. Considering the high level of policy intervention that the agricultural sector already has, a modeling approach that considers all the connections within it is essential; and the model presented in this study fulfills this requirement. In addition, the model presents a very detailed picture of the agricultural sector, with a high level of geographical detail aiming to identify local conditions that could influence the final economic consequences of climate change.

The model depicted here is a tool flexible enough to be applied in diverse situations in which information access is a constraint. As shown above, the main source of information here was the Agricultural Census, complemented with secondary data that should be easy to collect if the objective is to use this model in other countries.

Climate change impacts on the Chilean Agricultural sector are vast, with considerable economic consequences across regions. At the regional level, our model shows substantial re-allocations of land, with the northern zone showing larger changes. However, this land reallocation does not seriously impact the total agricultural production at the national level. Therefore, according to the results, even if climate change may not have large absolute consequences, it may produce large distributional consequences, with fruits producers being worst-off than crops producers. In this regard, climate change could threaten a key economic sector, since fruits account for 31% of the total food export. This redistribution of rents could worsen the inequity that already exists in Chile, presenting additional challenge for coping with climate change.

The statistical analysis suggests that the overall figures on net income computed under the climate change scenario, lay above to the 75th percentile.

In general, the results reported here are consistent with those reported by previous studies with large economic impacts on the northern zone. However, the ASM does not predict large economic consequences at the country level as previous studies did. Previous studies quantified the economic impacts of climate change, under the A2-2040 scenario, in losses equivalent to 10% of the agricultural income, while our results quantified those impacts in -3% of the agricultural income. This difference is related to the methodology used, in which the farmer maximizes the net income under different yield conditions.

However, besides the high level of detail in which the agricultural sector is modeled, some drawbacks remain and they should be considered in terms of future research needs. First of all, if our model considers a fine administrative disaggregation at commune level, results could be substantially improved by the inclusion of consideration of an agro-ecological zone disaggregation, thus providing a better representation of agro-climatic characteristics and their relationships with land suitability and productivity. Secondly, the magnitude of the projected impacts of climate change on the whole agricultural sector suggests that it is reasonable to suppose that changes in production will be large enough to drive change in agricultural prices. Due to the assumptions about prices, currently the ASM is not able to analyze this scenario. On solution could be move from supply modeling to sector modeling, or to general equilibrium modeling. The final choice will depend on the data availability.

Finally, the re-allocation of land across the country implies several impacts that are not modeled here, such as: environmental impacts due to land use changes, as well as social impacts. The latter suggests that the use of these types of models should be part of a more comprehensive impact analysis of the agricultural sector, with adequate consideration of the social component. This is very important considering the social consequences of changes in farming practices that are deeply rooted within the farmers' communities.

LITERATURE

1. Bates, B., Z. Kundzewicz, S. Wu, and J Palutikof. *Climate Change and Water.* Technical Paper, Intergovernmental Panel on Climate Change., Geneva: IPCC Secretariat, 2008.
2. Blanco, M, R Cortignani, and S Severini. "Evaluating Changes in Cropping Patterns due to the 2003 CAP Reform. An Ex-post Analysis of Different PMP Approaches Considering New Activities." *Modelling of Agricultural and Rural Development Policies.* Sevilla: EAAE, 2008.
3. CAPRI Model. "CAPRI Model Documentation." 2008.
4. CEPAL. *Economía del cambio climático en Chile. Síntesis.* CEPAL, 2009.
5. de Frahan, B, et al. "Positive Mathematical Programming for Agricultural and Environmental Policy Analysis: Review and Practice." In *Handbook Of Operations Research In Natural Resources*, by A Weintraub, C Romero, T Bjornda and R Epstein. Springer, 2007.
6. Foster, W, J Lopez, and A Valdes. "Impacto del Nivel de Distorsiones en el Sector Agrícola Nacional." Subsecretaria de Agricultura, 2011.
7. Hardaker, J., R. Huirne, and J. Anderson. *Coping with Risk in Agriculture.* Oxon: CAB International, 1997.
8. Hazzel, P, and R Norton. *Mathematical Programming For Economic Analysis in Agriculture.* New York: Collier Macmillan, 1986.
9. Heckelei, T, W. Britz, and Y. Zhang, "Positive Mathematical Programming Approaches – Recent Developments in Literature and Applied Modelling" *Bio-Based and Applied Economics* , 2012: 109-124.
10. Henseler, M, A Wirsig, S Herrmann, T Krimly, and S Dabbert. "Modeling the Impact of Global Change on Regional Agricultural Land use Through an Activity-based non-linear Programming Approach." *Agricultural Systems*, 2009: 31-42.
11. Howitt, R. "Agricultural and Environmental Policy Models: Calibration, Estimation and Optimization." University of Carlifornia. UCDavis, 2005.
12. Howitt, R. "Positive Mathematical Programming." *American Journal of Agricultural Economics*, 1995: 329-342.
13. Howitt, R, J Medellin-Azuara, and D Macewan. "Estimating the Economi Impacts of Agricultural Yield Related Changes for California." California Energy Comission, 2009.
14. Howitt, R, K Ward, and S Msangi. "Statewide Water and Agricultural Production Model. Apendix A." 2001.
15. Iglesias, E and M. Blanco. "New Directions in Water Resources Management: The Role of Water Pricing Policies". Water Resources Research, 2008.
16. INE. "Censo Agropecuario." 2007.
17. Intergovernmental Panel on Climate Change. *Special Report on Emisison Scenarios.* IPCC, IPCC, 2000.

18. Kan, I, D Haim, M Rapaport-Rom, and M Shechter. “Environmental amenities and optimal agricultural land use: The case of Israel.” *Ecological Economics*, 2009: 1893-1898.
19. Mattas, K, F Arfini, P Midmore, M Schmitz, and Y Schmitz. “CAP’s Impacts on Regional Employment: A Multi-Modelling Cross Country Approach.” In *Dissagregated Impacts of CAP Reforms: Proceeding of an OECD Workshop*, by OECD. Paris: OECD, 2011.
20. Medellín-Azuara, J, J Harou, and R Howitt. “Estimating Economic Value of Agricultural Water Under Changing Conditions and the Effects of Spatial Aggregation.” *Science of the Total Environment*, 2009.
21. ODEPA. *Estimación del impacto Socioeconómico del Cambio Climático en el Sector Silvoagropecuario de Chile.* ODEPA, ODEPA, 2010.
22. —. “Oficina de Politicas Agrarias.” 2010. www.odepa.cl (accessed 2012 on 09-07).
23. Quiroz, J, R Labán, and F Larraín. “El sector agrícola y agroindustrial frente a Nafta y Mercosur.” Sociedad Nacional de Agricultura, 1995.
24. Santibanez, F, P Santibanez, R Cabrera, L Solis, M Quiroz, and J Hernandez. *mpactos productivos en el sector silvoagropecuario de Chile frente a escenarios de Cambio Climático.* AGRIMED, AGRIMED, 2008.

(Tables and Figures)

Table 1. Climate Change Scenario: Average Expected Yields (ton/ha)

	Northern Zone		Central Zone		Southern Region	
Activity	Baseline	Climate Change	Baseline	Climate Change	Baseline	Climate Change
Crops	4	3.812	12.860	8.787	15.165	11.130
Alfalfa	13.459	13.809	18.442	19.790	21.376	24.488
Common Bean	1.320	0.532	1.710	1.469	1.275	1.170
Maize	6.380	3.886	9.473	7.947	6.925	6.204
Oat	3.026	2.790	2.465	1.437	3.177	4.055
Rainfed Potato	1.200	10.841	3.991	11.995	10.647	16.494
Irrigated Potato	10.146	4.177	12.699	8.785	14.898	18.031
Rice	0	0	5.046	2.920	4.252	2.283
Sugar Beet	0	0	67.333	27.600	81.461	30.957
Rainfed Wheat	1.928	1.689	2.782	1.852	3.683	4.278
Irrigated Wheat	2.543	0.399	4.664	4.073	3.958	3.338
Fruits	14.805	5.524	16.035	13.142	12.746	10.044
Apple	28.571	4.605	34.376	19.114	30.328	27.159
Avocado	8.003	7.490	8.704	10.212	9.437	4.226
Cherry	6.550	1.913	5.313	5.023	3.206	3.335
Grapes	19.140	5.132	20.951	16.292	15.319	12.248
Olive	10.979	4.310	12.760	11.316	13.026	7.476
Orange	18.798	16.671	20.350	23.585	19.479	9.759
Peach	22.796	7.693	22.980	20.197	13.836	13.344
Pear	12.171	2.057	15.274	8.625	16.108	12.133
Plum	23.085	6.985	21.836	18.339	8.525	12.116
Vineyard	9.864	2.941	11.151	9.337	8.787	7.020
Walnut	2.892	0.969	2.693	2.525	2.154	1.668
Forest	0.113	0.088	0.194	0.169	0.235	0.265
Pine	0.177	0.107	0.240	0.200	0.291	0.317
Eucalyptus	0.049	0.068	0.148	0.138	0.179	0.212

Table 2. Economic Impacts of Climate Change (Million USD)

Region	Baseline	Climate Change
Atacama	13	4
Coquimbo	112	46
Valparaiso	202	156
Metropolitana	186	111
Ohiggins	388	373
Maule	430	398
Biobio	453	494
Araucania	297	363
Los Rios	105	130
Los Lagos	50	101
Total	2,235	2,176

Figure 1. Cumulative Distribution Function: Agricultural Net Income.